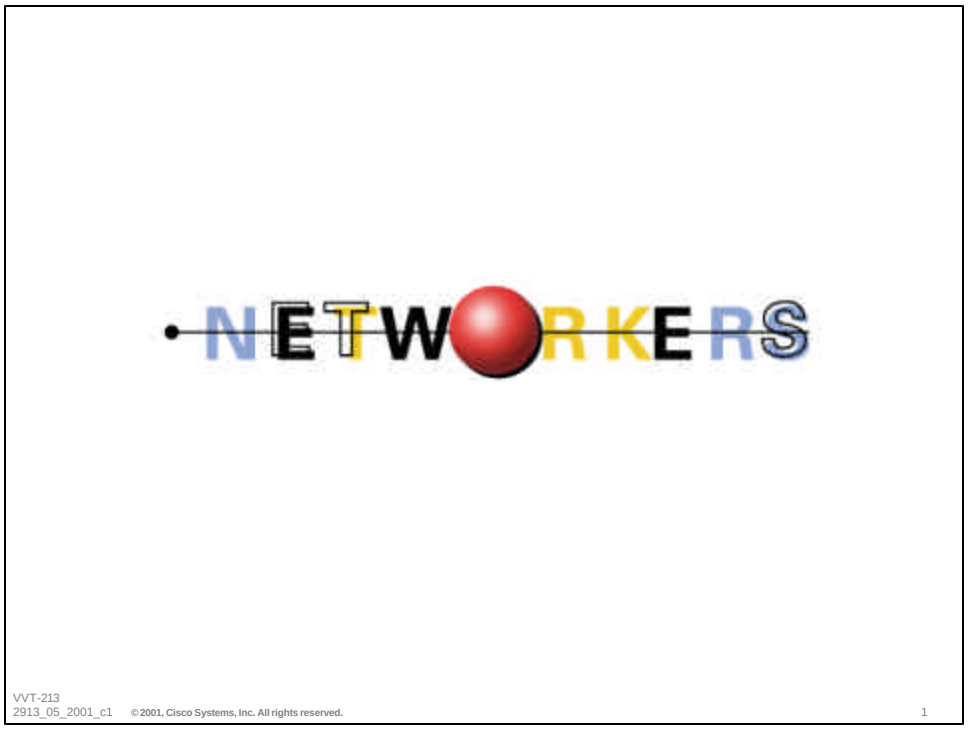

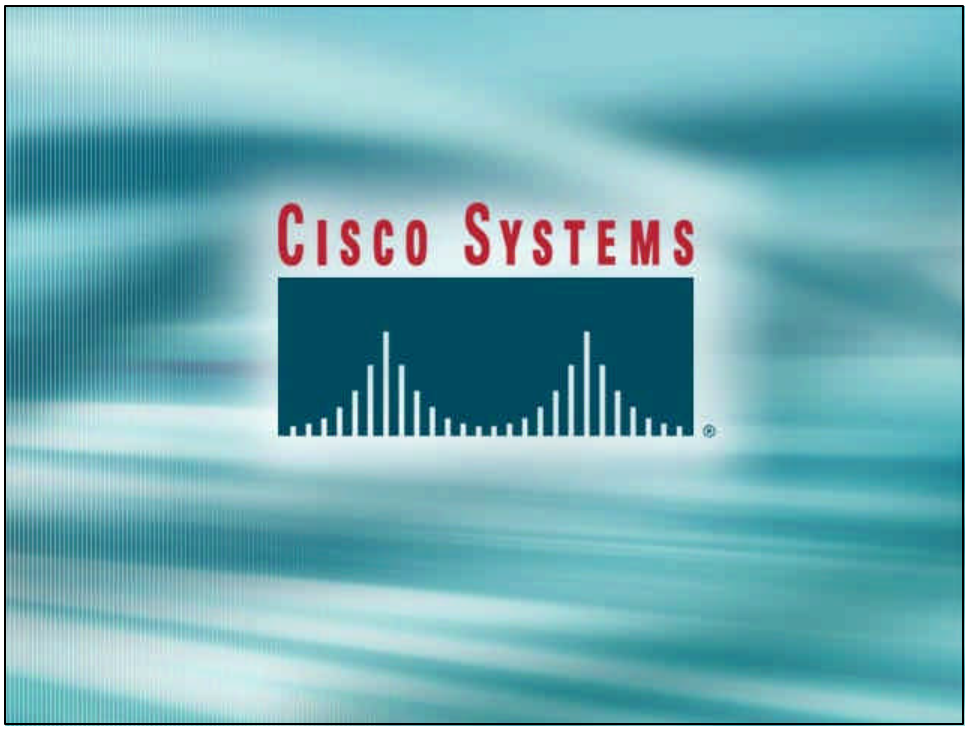

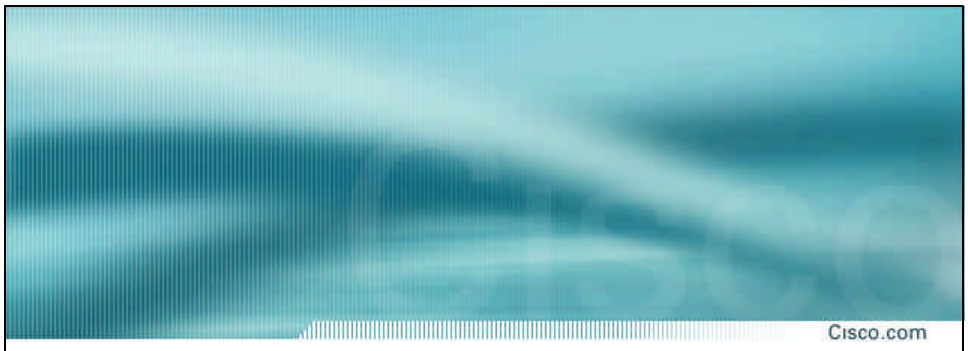

Deploying QoS for Voice and Video in IP Networks

Session VVT-213

Session Objectives

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- To be able to design and implement an AVVID infrastructure that can guarantee voice quality while enabling video conferencing, streaming video and mission critical data applications
- Presentation follows the IP telephony QoS design guide on CCO
  http://www.cisco.com/univercd/cc/td/doc/product/voice/ip_tele/avvidqos/index.htm
- All designs based on:
  - Cisco CallManager 3.1 and above
  - CatOS 5.5(8) and Cat IOS 12.1(2)E and above
  - IOS 12.1(2)T-12.1(5)T and above

The AVVID Design Model

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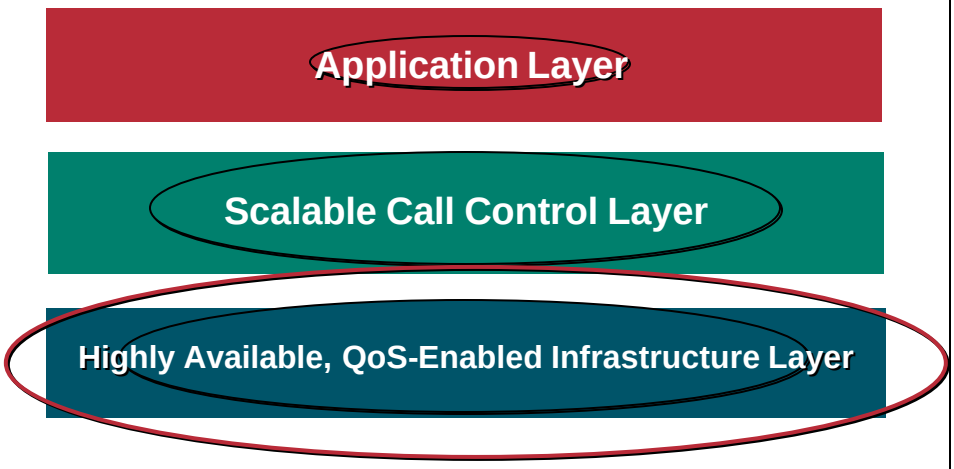
The OSI Stack Revisited



3 Steps for CoS/QoS Implementation

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- **Classification**—Marking the packet with a specific priority denoting a requirement for special service from the network
- **Scheduling**—Assigning packets to one of multiple queues (based on classification) for expedited treatment through the network
- **Provisioning**—Accurately calculating the required bandwidth for all applications plus element overhead

QoS is Needed to Minimize Packet Loss, Delay and Delay Variation

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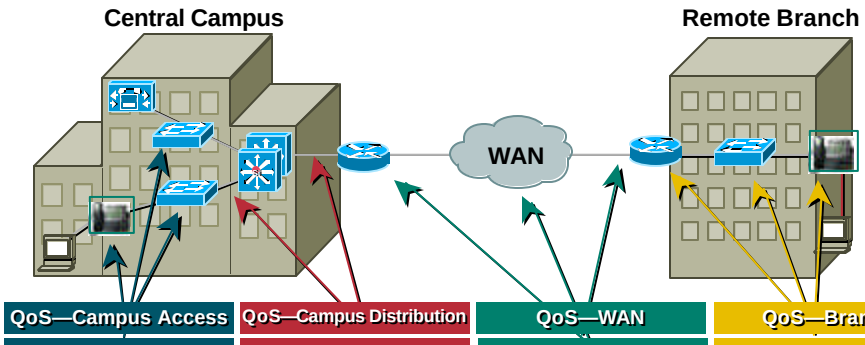
Where QoS Is Needed



QoS—Campus Access	QoS—Campus Distribution	QoS—WAN	QoS—Branch
Speed and Duplex Settings Classification/trust on IP Phone and Access Switch Multiple Queues on IP Phone and Access Ports	Layer 3 Policing Multiple Queues on All Ports; Priority Queuing for Voip WRED Within Data Queue for Congestion Management	Low-latency Queuing Link Fragmentation and Interleave Bandwidth Provisioning Admission Control	Classification and Trust Boundaries on IP Phone , Access Layer Switch and Router Multiple Queues on IP Phone and All Access Ports

Agenda

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- Quality Concerns with IP Telephony and Multimedia Applications
- General AVVID QoS Design Guidelines
- Connecting the IP Phone
- Designing the Campus
- Enabling the WAN
- Managing the QoS Infrastructure

Factors which Degrade Voice Quality

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Packet Loss

- **Packet loss**
  - Current Cisco GW DSP CODEC algorithms can correct for 30 msec of lost voice—1 G.729A voice packet contains 20 msec of voice
  - Lost packets induce “clipping” and temporarily expand the jitter buffer, which increases end-to-end latency
  - One lost FAX over IP packet causes a MODEM retrain; 2 drops cause a call disconnect
  - Causes of packet loss: Network quality, network congestion and delay variation (jitter buffer under-runs)

Factors which Degrade Voice Quality

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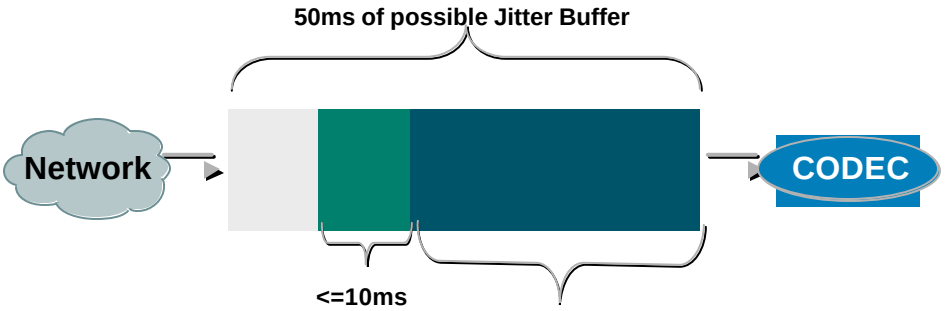
Variable Delay—Jitter Buffer Under Runs

Cisco GW DSPs Uses an Adaptive Jitter Buffer Which Only Has 10 msec of “Extra” Buffer

Packet Dropped If Instantaneous Jitter Is > 10 msec



Calculated Jitter Buffer Based on Variable Network Delay in msec (packet RTP Timestamp)

Factors which Degrade Voice Quality

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End-to-End Delay

ITU G.114 states one-way delay <= 150 msec ~200 msec is acceptable

- CODEC
  - G.729A = 25 msec (20msec+5msec look ahead)
- Queuing
  - Queuing delay = serialization delay as utilization approaches 100%
- Serialization
- Propagation and network delay
  - 6.3 usec/km + network delay (variable)
- Jitter buffer
  - 20-50 msec

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Example of PCM (64Kbps) IP Telephony Call

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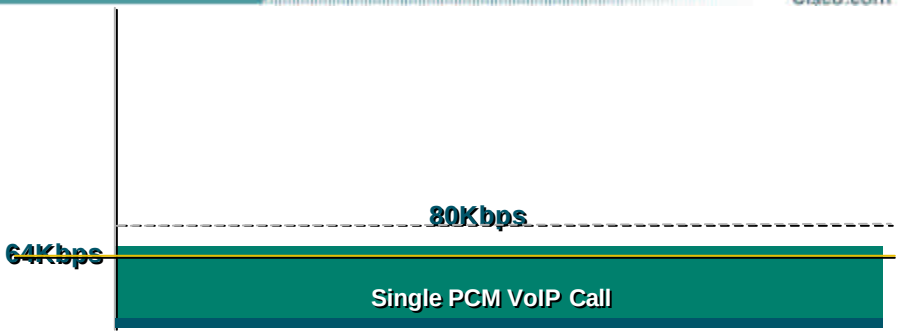

- Consistent, easily managed packet rate
- A G.711 call is really 80Kbps over a data network
- Layer 2 overhead not included
- VAD/silence suppression is not enabled in this example

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Factors which Degrade Video Conferencing Quality

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- Unlike voice, video has a very high, extremely variable packet rate
- Much higher average MTU
- Queuing
  - The LLQ will fill to capacity regularly
  - Queuing delay = serialization delay as utilization approaches 100%
- End-to-end delay
  - 200 msec target delay budget
- Jitter buffer
  - 20-70 msec

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Example of 384 Kbps Video (30 fps) Conferencing Traffic (CIF)

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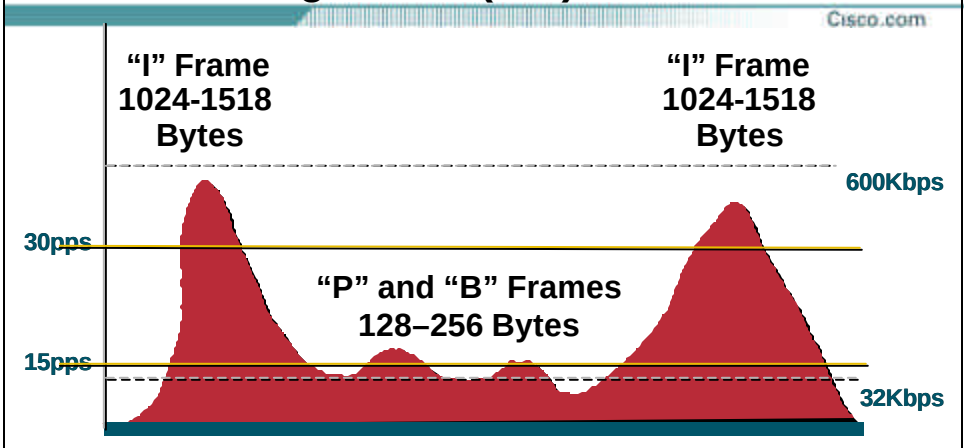

- "I" frame is a full sample of the video
- "P" and "B" frames use quantization via motion vectors and prediction algorithms

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Video Conferencing Traffic Packet Size Breakdown (CIF)

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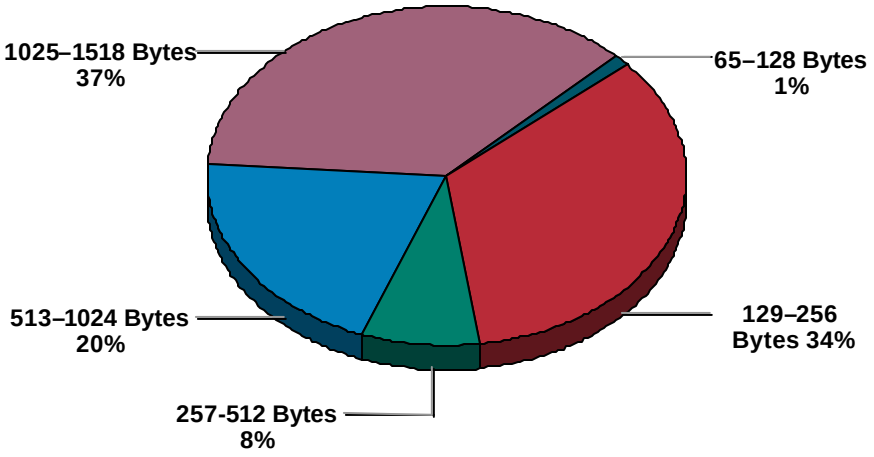

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Video Conferencing Traffic Packets per Second Breakdown (CIF)

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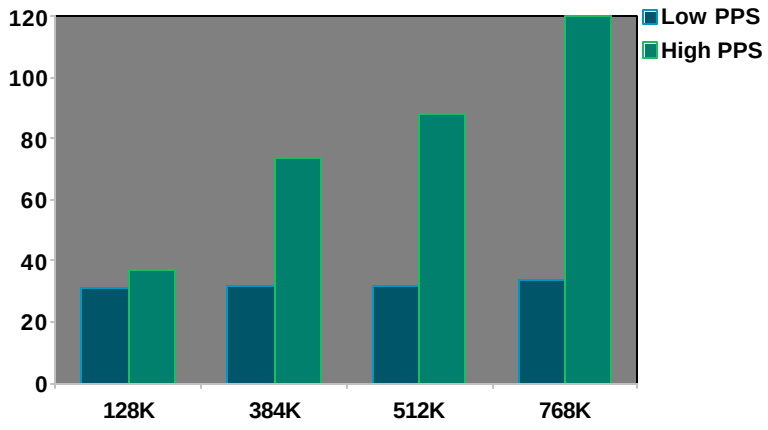

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Factors which Degrade Streaming Video Quality

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- Has a very high, extremely variable packet rate
- Much higher average MTU
- Queuing

  Because of the tolerance for e-2-e delay, streaming video should go into a bw-based queue

- End-to-end delay

  4–5 secs

- Jitter buffer

  1 MB (read long latency tolerance)

Streaming Video Traffic Packet Size Breakdown (MPEG-1)

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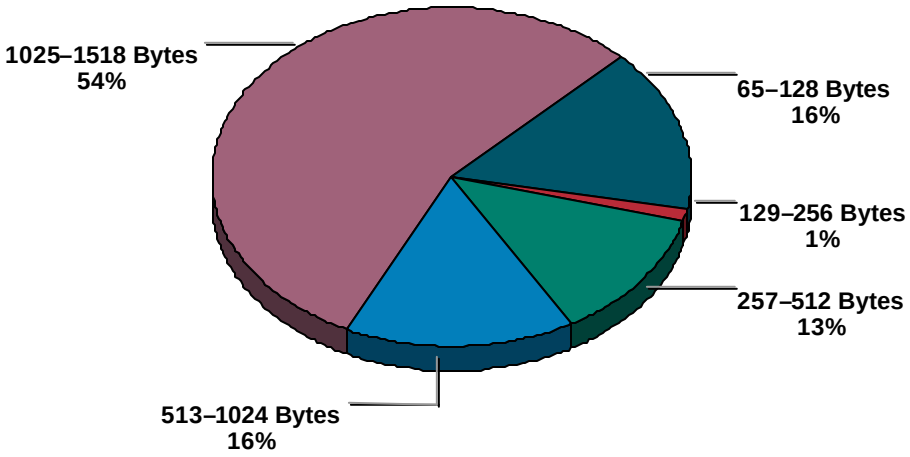

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Layer 2 Class of Service

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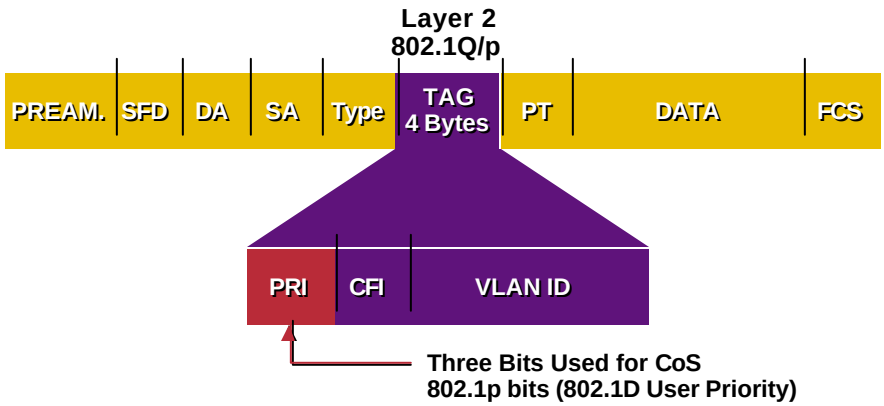

Note: IP Phones Do Not Support ISL

Layer 3 Type of Service

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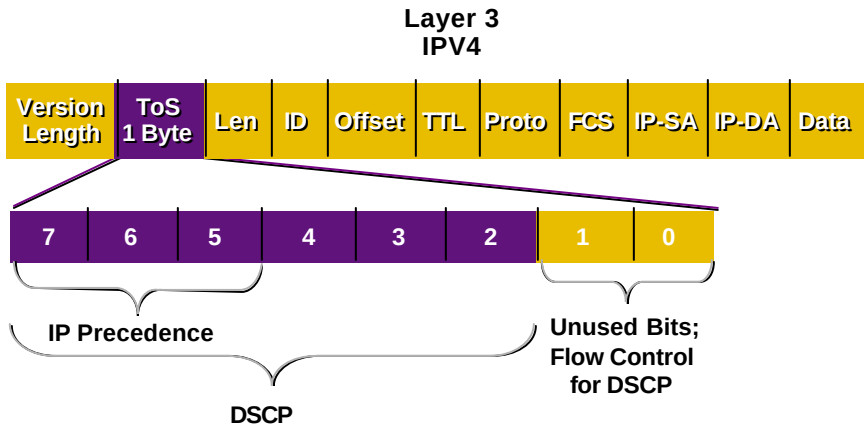

Standard IPV4: Three MSB Called IP Precedence
(DiffServ May Use Six D.S. Bits Plus Two for Flow Control)

Differentiated Services Code Point (DSCP)

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- Fundamentally, just a way to classify, or differentiate traffic
- A number placed in the IP header to assist in isolating a class of traffic
- Occupies 6 bits out of what used to be the TOS byte
- The other two bits are for Explicit Congestion Notification (ECN)
- Typically used in conjunction with a Per-Hop Behavior (PHB)

  E.g., RFC (EF PHB-2598 or AF PHB-2597)

Defined Per-Hop Behaviors

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- **EF**

  EF PHB (Expedited Forwarding—RFC 2598) can be used to build a low loss, low-latency, low jitter, assured bandwidth, end-to-end service

  "Virtual leased-line"

- **AFxy**

  AF PHB (Assured Forwarding—RFC 2597) gives domains the ability to offer different levels of traffic forwarding assurance

  x = 4 AF classes are defined (AF1y-AF4y)

  y = 3 drop preferences/probabilities per class

- **Best effort**

Diff-Serv Behaviors

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Per-Hop Behaviours (PHB)				DiffServ Code Points (DSCP)		
Expedited Forwarding	EF			101110		
Assured Forwarding	Low Drop Pref	Med Drop Pref	High Drop Pref			
Class 1	AF11	AF12	AF13	001010	001100	001110
Class 2	AF21	AF22	AF23	010010	010100	010110
Class 3	AF31	AF32	AF33	011010	011100	011110
Class 4	AF41	AF42	AF43	100010	100100	100110
Best Effort				000000		

Cisco AVVID Classification

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Voice with the "Encore" CallManager Release

- **Voice**
  - **VoIP control channels**
    - CoS = 3, IP Prec = 3, DSCP = AF31
    - H.323 = TCP 1720, 11xxx (RAS = TCP 1719) 12.2(1)T
    - Skinny = TCP 2000-200 CCM 3.0(5)
    - ICCP = TCP 8001-8002 CCM 3.0(8)
    - CTI (TAPI/JTAPI) = TCP 2748
    - MGCP = UDP 2427, TCP 2428 CCM 3.1
  - **VoIP RTP bearer channels**
    - CoS = 5, IP Prec = 5, DSCP = EF
    - UDP 16384-32767 CCM 3.0+ and IOS 11.3+

Cisco AVVID Classification (Cont.)

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Video Classification

- **Video**
  - **Video conferencing**
    - CoS = 4, IP Prec = 4, DSCP = AF41
    - RAS = TCP 1719, H.323 = TCP 1720 & 11xxx, UDP = Depends...
  - **Streaming video (IP/TV)**
    - CoS = 1, IP Prec = 1, DSCP = AF13—Recommended for enterprises
    - UDP = IP/TV 3.2 provides customer port configuration
      - http://www.cisco.com/warp/customer/cc/pd/mxsv/iptv3400/tech/ipqos_wp.htm
  - **3rd party video partners**
    - VCON—Can set ToS
      - http://techsup.vcon.com/Docs/ToS-setting%20utility.doc
    - PictureTel—Can set ToS
    - Polycom—Can set ToS
    - RadVision—Can not set ToS

Cisco AVVID Classification, Cont.

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Data Application Classification

- **Data**
  - **CoS = 0-2, IP Prec = 0-2, DSCP = 0-AF23**
  - **Some data applications may need special handling from the network**
  - **This can be for business, technical or Layer 8 reasons**
- **Recommendations**
  - **Only classify when necessary**
  - **Modifying WRED thresholds may be required to insure performance**
    - **For a CoS/ToS = 2 applications, configure queue #1's 2nd threshold (CoS/ToS = 2) to drop at 95% instead of 50%**

Connecting the IP Phone

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General Guidelines

- **Use auto-negotiation on the wiring closet switch port and PC NIC**
- **Separate all voice traffic onto a voice specific subnet**
- **Use portfast to decrease IP phone boot time**
- **IP Phone VoIP RTP bearer traffic will use CoS/ToS=5/EF**
- **Classify all VoIP control traffic to CoS/ToS=3/AF31**
- **Extend and enforce trust boundary at IP phone (set port qos <mod/port> trust-ext ___); never allow PC applications to send traffic at CoS/ToS 5-7 except SoftPhone**

Designing the Campus

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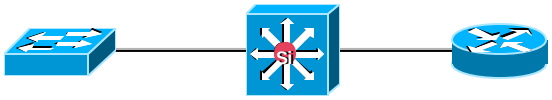
General Guidelines



- A robust, modern switching design is a requirement
  - http://www.cisco.com/warp/public/cc/so/cuso/epso/entdes/highd_wp.htm
  - http://www.cisco.com/warp/public/cc/so/neso/lnso/cpso/camp_wp.htm
- Multiple queues are required on all interfaces to guarantee voice quality
  - 2900 XL (8 MB DRAM), 3500 XL, 4000, 6000
- Catalyst 5000 designs should use a separate path for voice traffic
- Voice RTP bearer traffic should always go into the highest priority queue; video and voice call control should go into queue #2 regardless of device
- Distribution layer switches must have the ability to map between CoS and ToS values

Building the Branch Office

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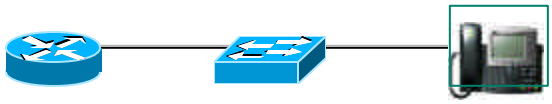
General Guidelines



- The WAN branch router MUST support advanced Cisco QoS tools
- Use 12.2(1)T* in the router to map between layer 2 and layer 3 classification schemes
- Use a branch switch with multiple queues
- 802.1Q trunking between the router and switch for multiple VLAN support (separation of voice/data traffic) is preferred

Enabling the WAN

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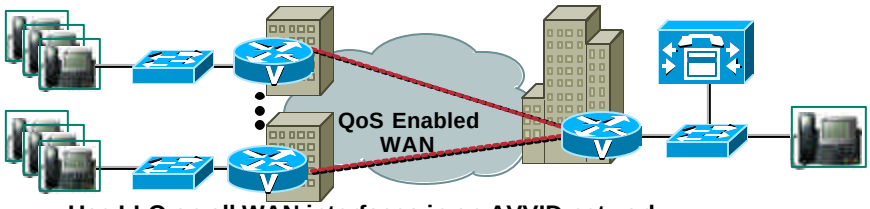
General Guidelines



- Use LLQ on all WAN interfaces in an AVVID network
  - Voice (DSCP=EF) † LLQ
  - Video conferencing (DSCP=AF41) † LLQ (conferencing)
  - Call control (DSCP=AF31) † CBWFQ (minimum 8Kbps)
  - Streaming video (DSCP=AF13) † CBWFQ (Kbps depends upon IP/TV policy)
- Use LFI on WAN connections below 768Kbps
  - Don't use LFI on any video over IP solutions
- Traffic shaping is required for all frame-relay and ATM/FR networks
- Use cRTP carefully; pay attention to the IOS and interface caveats
- Call admission control is required when the number of calls can overwhelm the provisioned LLQ (PQ) bandwidth

Agenda

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- Quality concerns with IP Telephony and Multimedia Applications
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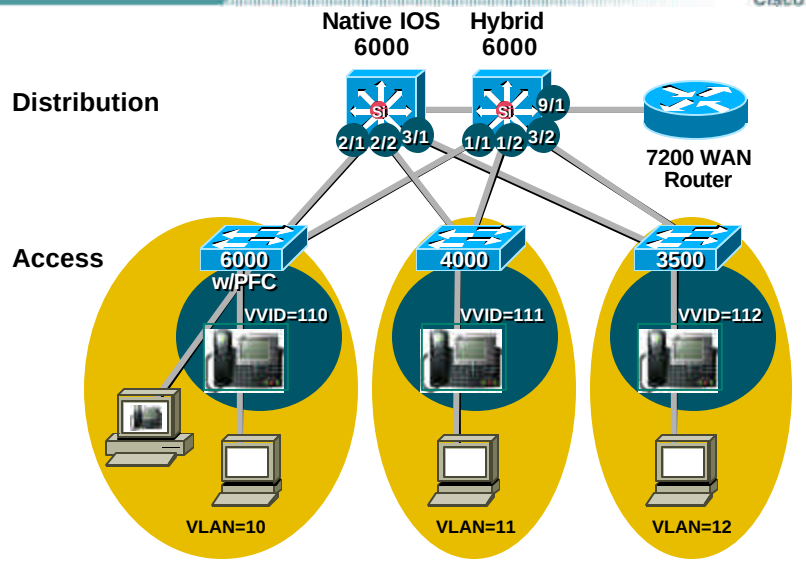
Example AVVID QoS Network—Campus



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Cisco IP Phone Port Speed and Duplex

Single Cable

- Cisco IP phone ports auto-negotiate; not user configurable until CCM 3.1(x); best practice: set switch port to auto-negotiation

```
cat6k-access> (enable) set port speed 5/1-48 auto

cat3500(config)# interface FastEthernet0/1
cat3500(config-int)# speed auto
```

- If the PC NIC or switch is configured to full/100, the phone will negotiate to half/100

  How auto-neg works: http://www.cisco.com/warp/customer/473/3.htm

  Troubleshooting auto-neg: http://www.cisco.com/warp/customer/473/46.html

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Connecting the IP Phone

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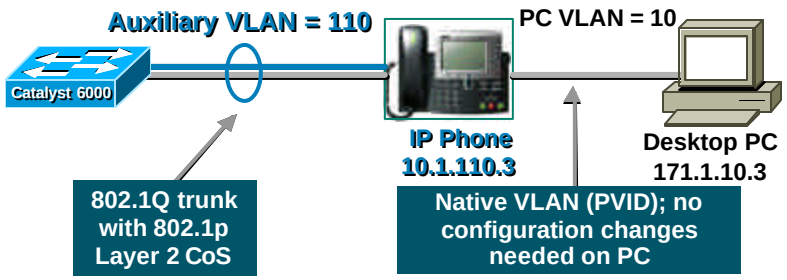
Catalyst 4000 and 6000—Single Cable




```
cat6k-access> (enable) set vlan 10 name 171.1.10.0_data
cat6k-access> (enable) set vlan 110 name 10.1.110.0_voice
cat6k-access> (enable) set vlan 10 5/1-48
cat6k-access> (enable) set port auxiliaryvlan 5/1-48 110
cat6k-access> (enable) set port speed 5/1-48 auto
cat6k-access> (enable) set port host 5/1-48
```


Connecting the IP Phone

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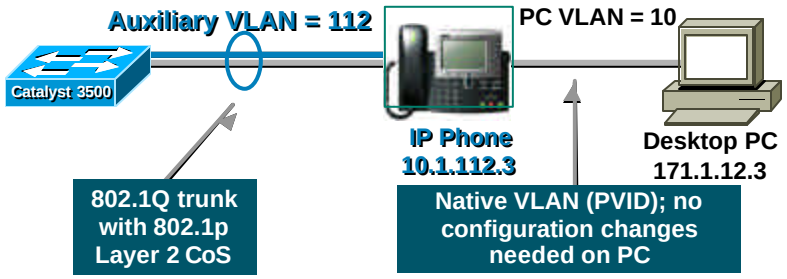
Catalyst 3500—Single Cable




```
interface FastEthernet0/1
    switchport trunk encapsulation dot1q
    switchport trunk native vlan 12
    switchport mode trunk
    switchport voice vlan 112
    speed auto
    spanning-tree portfast
vlan database
    vlan 112
```

Queuing on the IP Phone

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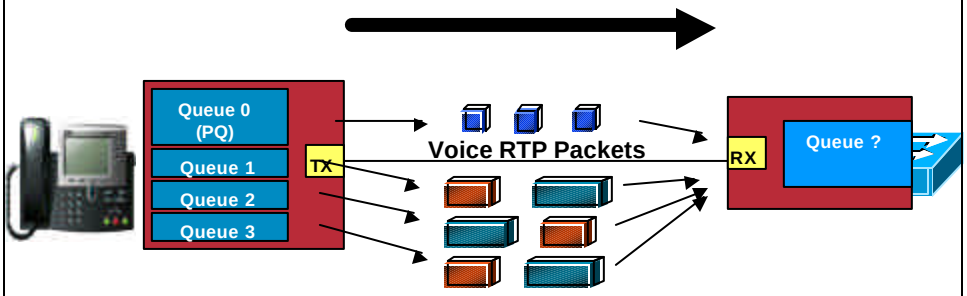


- PQ Is for CoS=5 Flows and BPDUs
- Round-Robin Scheduling with a PQ Timer
- Access Layer switch RX queue can be: FIFO, 1Q4T or 1P1Q4T (Future)

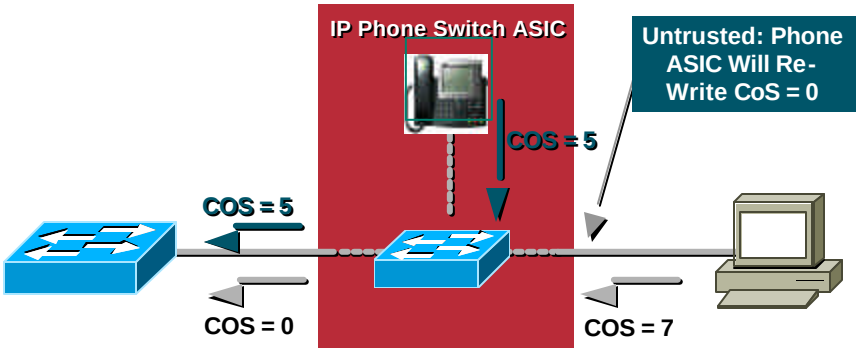
PC CoS Settings Are Not Trusted

Cisco.com

Default—Recommended

```
cat6k (enable)#  set port qos 2/1 trust-ext untrusted

cat3500(config)# interface FastEthernet0/1
cat3500(config-int)# switchport priority extend cos 0
```



Port Trust on the Catalyst 6000

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- set port qos <mod/port> trust-ext _____
  - Only applies to port trust on the IP phone PC ethernet port
  - Un-related to actual cat6k port trust
- set port qos <mod/port> trust _____
  - Applies to the actual cat6k port trust rules
  - untrusted (default), trust-cos, trust-ipprec, trust-dscp
  - Current 10/100 cards require an additional ACL to actually enable port trust:

```
cat6k-access> (enable) set qos enable
cat6k-access> (enable) set port qos 5/1-48 trust trust-cos
cat6k-access> (enable) set port qos 5/1-48 vlan-based
cat6k-access> (enable) set qos acl ip ACL_IP-PHONES
trust-cos ip any any
cat6k-access> (enable) commit qos acl all
cat6k-access> (enable) set qos acl map ACL_IP-PHONES 110
```


Connecting the IP Phone

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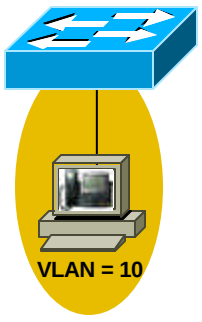
SoftPhone

- SoftPhone sets VoIP-RTP to DSCP = EF
- No CoS manipulation
- No VoIP control plane classification
- Trusting the SoftPhone DSCP settings requires trusting all DSCP tags from the PC




```
cat6k-access> (enable) set vlan 10 6/1-24
cat6k-access> (enable) set port host 6/1-24
cat6k-access> (enable) set port qos 6/1-24 trust trust-dscp
```

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Is QoS Needed in the Campus?

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"Just throw more bandwidth at it. That will solve the problem!"

Maybe, Maybe Not; Campus Congestion Is a Buffer Management Issue

Access, Distribution and Core Queuing

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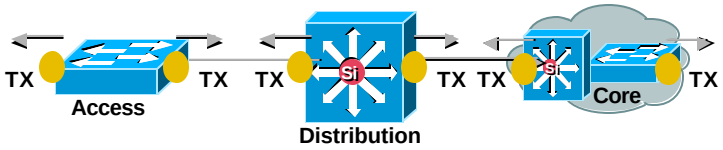
Area's Where QoS Maybe a Concern



- Output buffers can reach 100% in campus networks
- When an output buffer congests, dropped packets occur at the ingress interfaces
- QoS required when there is a possibility of congestion in buffers
- Multiple queues are the only way to "guarantee" voice quality

Tx Buffer Congestion

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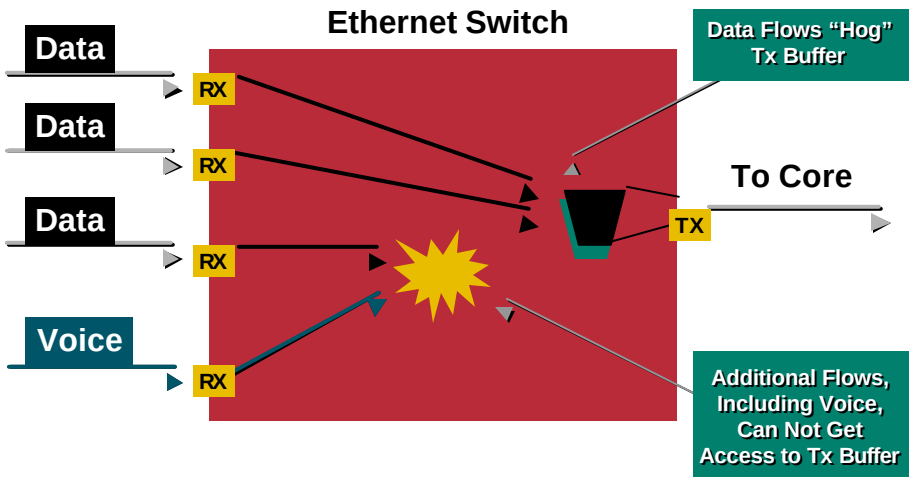

Guaranteed Voice Requires Multiple Queues

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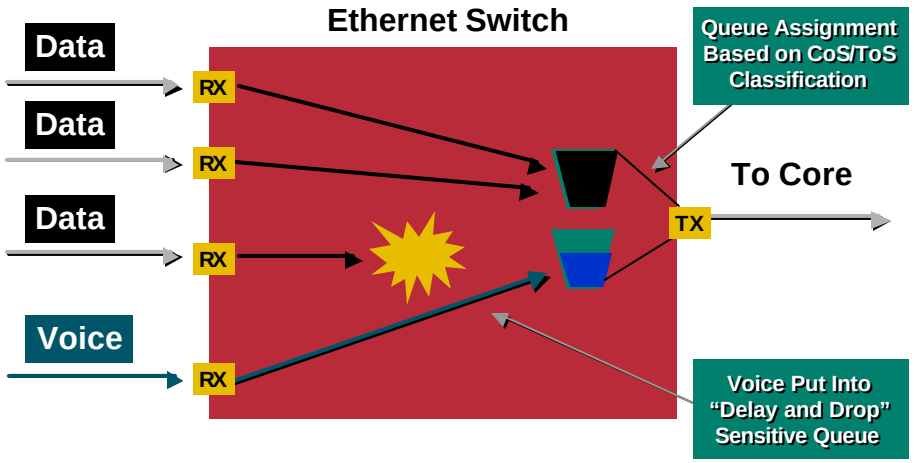

Queues Transmit Scheduled on RR/WRR Format

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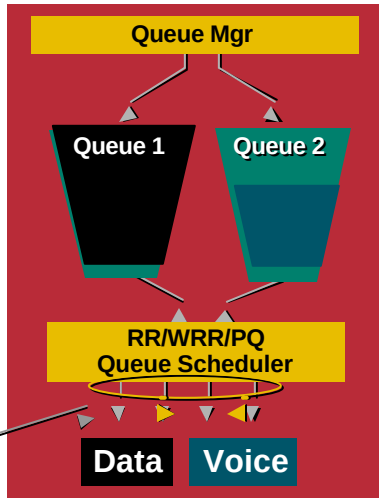
- **Catalyst 6000**
  - WRR or PQ/WRR
  - WRR is a 255:5 ratio of high/low queues
- **Catalyst 4000**
  - Round-Robin
- **Catalyst 2900 XL and 3500 XL**
  - Exhaustive PQ'ing scheme
- **IP Phone**
  - Round-Robin with a priority timer for PQ



Round Robin, Weighted Round Robin or Priority Queuing Used for Scheduling Between Queues

Campus QoS

Cisco.com

Catalyst Switches which Support Multiple Queues

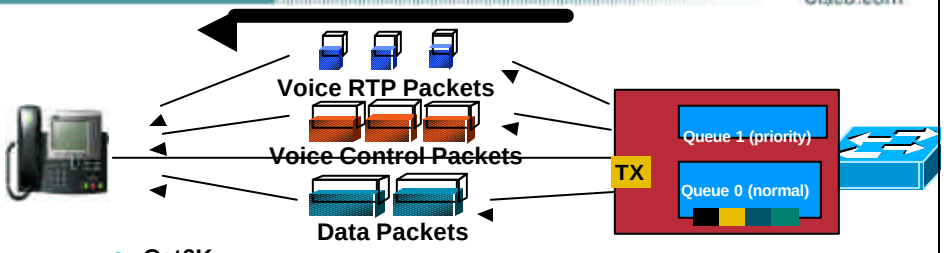
Queuing/Scheduling Capabilities Depend on Hardware:

- **Wiring Closet**
  - 3500—2Q1T TX (10/100 Mbps)
    - 8Q1T TX (1000 Mbps—Only 2 active)
  - 4000—2Q1T TX (10/100/1000 Mbps)
  - 6000—2Q2T TX (10/100/1000 Mbps)
    - 1P2Q2T TX (1000 Mbps)*
    - 1Q4T RX (10/100/1000 Mbps)
    - 1P1Q4T RX (1000 Mbps)*
- **Distribution/Core**
  - 6000—2Q2T TX (10/100/1000 Mbps)
    - 1P2Q2T TX (1000 Mbps)
    - 1Q4T RX (10/100/1000 Mbps)
    - 1P1Q4T RX (1000 Mbps)

* Next generation Cat6k 10/100 Linecards will be able to take advantage of the additional PQ

Access Switch 10/100 Port TX Queuing

Cisco.com



- **Cat6K**
  - Cat6K 10/100BaseT Interface has 2Q2T TX Queue
  - WRR Between Queues (255:5 Ratio of High/Normal)
- **Cat4K**
  - Cat4K 10/100BaseT Interface has 2Q1T TX Queue
  - RR Between Queues
- **Cat 3500 XL**
  - 2900 XL and 3500 XL 10/100BaseT Interfaces have 2Q1T TX Queue
  - Exhaustive PQ'ing Scheme (not configurable)

QoS In Catalyst 6000 Switches

Cisco.com

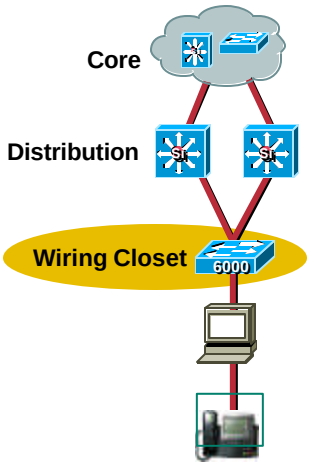
Access Layer—Cat6K

- Port can trust DSCP, IP Prec or CoS
  - Recommended: trust-cos
  - 10/100 cards require an additional step of configuring ACL to trust traffic
- Any traffic which "hits" the MSFC will receive a CoS of "0"...DSCP and CoS map required
- Current 10/100 Cards don't have the additional TX and RX PQs
- Only switch which really can support SoftPhone QoS
- Output scheduling consists of:
  - Assigning traffic to queues based on CoS
  - Configuring threshold levels
  - Modifying buffer sizes (expert mode)
  - Assigning weights for WRR (expert mode)

Catalyst 6000 Example

Cisco.com

Access Layer—Cat6K




```
cat6k-access> (enable) set qos enable
cat6k-access> (enable) set qos acl ip ACL_IP-PHONES
  trust-cos ip any any
cat6k-access> (enable) set qos acl ip ACL_VIDEO-CONF
  trust-ipprec ip host 10.70.247.200 any
cat6k-access> (enable) set qos acl ip ACL_IPTV trust-
  ipprec ip any any
cat6k-access> (enable) set port qos 5/1-48 trust trust-
  cos
cat6k-access> (enable) set port qos 5/1-48 vlan-based
cat6k-access> (enable) set port qos 4/2,4 port-based
cat6k-access> (enable) commit qos acl all
cat6k-access> (enable) set qos acl map ACL_IP-PHONES 110
cat6k-access> (enable) set qos acl map ACL_VIDEO-CONF 4/2
cat6k-access> (enable) set qos acl map ACL_IPTV 4/4
cat6k-access> (enable) set qos map 1p2q2t tx 2 1 cos 3
cat6k-access> (enable) set qos map 2q2t tx 2 1 cos 3
cat6k-distrib> (enable) set qos cos-dscp-map 0 14 16 26
  34 46 48 56
cat6k-distrib> (enable) set qos ipprec-dscp-map 0 14 16
  26 34 46 48 56
cat6k-access> (enable) set port qos 1/1-2 trust trust-cos
```

QoS in Catalyst 4000/2948G

Cisco.com

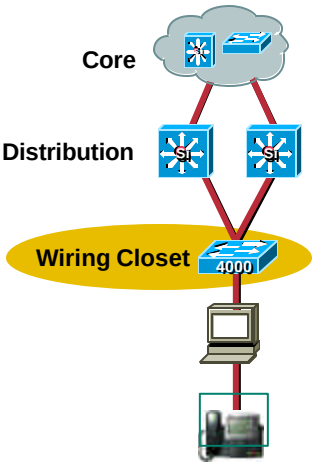
Access Layer—Cat4K

- Input classification based on incoming CoS label (802.1p)
- If no CoS, packet gets assigned a CoS value which is “switch-wide”
- All ports are considered “trusted”
- The output ports have a 2Q1T capability
- CoS values mapped to output queues in pairs
- Queues are serviced in a round-robin fashion

Catalyst 4000/2948G Example

Cisco.com

Access Layer—Cat4K




```
cat4k> (enable) set qos enable
cat4k> (enable) set qos map 2q1t 1 1 cos 0-1
cat4k> (enable) set qos map 2q1t 2 1 cos 2-3
cat4k> (enable) set qos map 2q1t 2 1 cos 4-5
cat4k> (enable) set qos map 2q1t 2 1 cos 6-7

cat4k> (enable) show qos info runtime
Run time setting of QoS:
QoS is enabled
All ports have 2 transmit queues with 1 drop
thresholds (2q1t).
Default CoS = 0
Queue and Threshold Mapping:
Queue Threshold CoS
----- --------- ---------------
1     1         0 1
2     1         2 3 4 5 6 7
```

Queue CoS mapping occurs in groups of 2

QoS in Catalyst 3500/2900 XL

Cisco.com

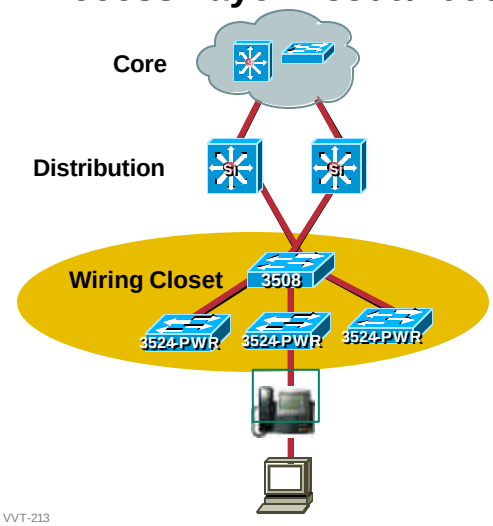
Access Layer—3500/2900 XL

- Input classification based on incoming CoS label (802.1p)
- If no CoS, packet can be assigned a port-based CoS value
- The ports have a 2Q1T TX capability
- CoS values mapped to default output queues—not configurable
  - 0-3 = Low Priority Queue
  - 4-7 = High Priority Queue
- Queues are serviced via priority scheduling
- GigaStack architecture is not supported for guaranteed voice quality because it's a shared media
- No way to view queue configuration and statistics with the current HW
- 2900 XL requires 8 MB DRAM

Catalyst 3500/2900 XL Example

Cisco.com

Access Layer—3500/2900 XL




```
interface FastEthernet0/1
 power inline auto
 speed auto
 switchport trunk encapsulation dot1q
 switchport trunk native vlan 12
 switchport mode trunk
 switchport voice vlan 112
 switchport priority extend cos 0
 spanning-tree portfast
interface GigabitEthernet0/1
 switchport trunk encapsulation dot1q
 switchport mode trunk

vlan database (EXEC Mode)
 vlan 112
```


QoS Is Catalyst 6000 Switches

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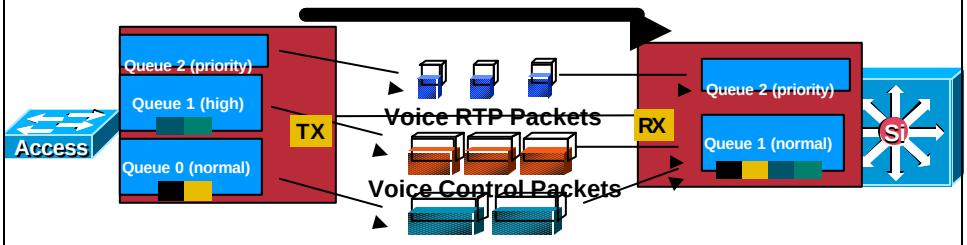
Distribution Layer—Cat6K

- Typically Gig-E for all connections
  - TX = 1P2Q2T
  - RX = 1P1Q4T
- Use dual layer 3 distribution layer switches and load balance VLANs using HSRP; tweak STP, HSRP and routing protocols for fast convergence
- Distribution layer switch will perform all Layer 3 ✝ Layer 2 classification mapping for layer 2 only access switches
- Any frames which "hit" the MSFC will receive a CoS value of "0": mark DSCP and perform DSCP to CoS mappings
- "Trust" access layer switch CoS markings

Cat6K Access-Distribution Gig-E Uplink

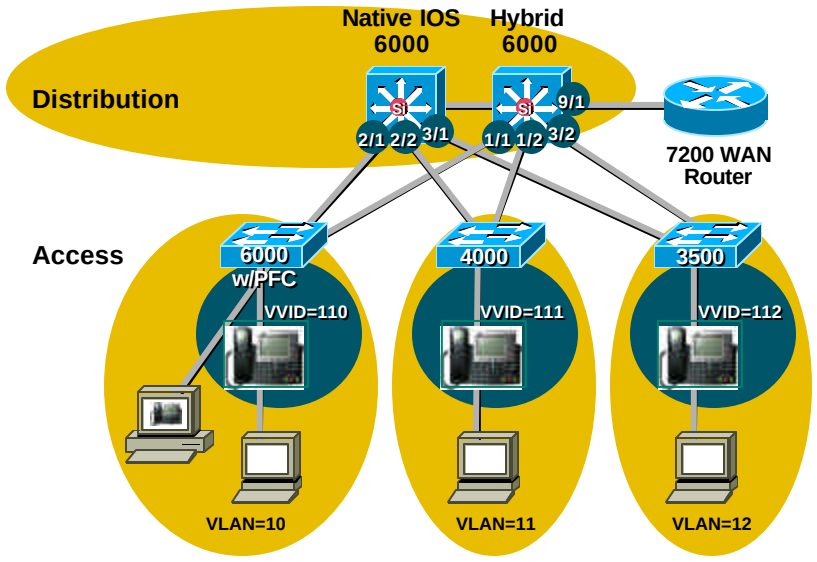
Cisco.com



- Cat6K Gig-E has 1P2Q2T TX Interface Queue
- Cat6K Gig-E Interface has a 1P1Q4T RX Queue
- PQ/WRR Queue Scheduler
- RX PQ gives frames priority access to backplane
- Must "trust" CoS for RX PQ Access

Example AVVID QoS Network—Campus

Cisco.com



Catalyst 6000 Example—Hybrid

Cisco.com

Distribution Layer—Cat6K

Hybrid
6000

```
cat6k-access> (enable) set qos enable
cat6k-distrib> (enable) set qos map 1p2q2t tx queue 2 1 cos 3
cat6k-distrib> (enable) set qos map 2q2t tx queue 2 1 cos 3
cat6k-distrib> (enable) set qos ipprec-dscp-map 0 14 16 26 34 46 48 56
cat6k-distrib> (enable) set qos cos-dscp-map 0 14 16 26 34 46 48 56
cat6k-distrib> (enable) set port qos 1/1-2,3/2 trust trust-cos
cat6k-distrib> (enable) set port qos 1/1-2,3/2 vlan-based
cat6k-distrib> (enable) set port qos 9/1 trust trust-dscp
cat6k-distrib> (enable) set port qos 9/1 port-based
cat6k-distrib> (enable) set qos acl ip ACL_TRUST-WAN trust-dscp ip any
any
cat6k-distrib> (enable) commit qos acl ACL_TRUST-WAN
cat6k-distrib> (enable) set qos acl map ACL_TRUST-WAN 9/1
```


Catalyst 6000 Example—Native

Cisco.com

Distribution Layer—Cat6K

```
mls qos
mls qos map ip-prec-dscp 0 14 16 26 34 46 48 56
mls qos map cos-dscp 0 14 16 26 34 46 48 56
int range gigabitEthernet 1/1 - 2
     wrr-queue cos-map 2 1 3
     wrr-queue cos-map 2 2 4

! Trust CoS from the PFC enabled Access Switch
interface GigabitEthernet2/1
     description trunk port to PFC enabled cat6k-access
     no ip address
     wrr-queue cos-map 2 1 3
     wrr-queue cos-map 2 2 4
     mls qos vlan-based
     mls qos trust cos
     switchport
     switchport trunk encapsulation dot1q
     switchport mode trunk
```

Native-IOS 6000

Catalyst 6000 Example—Native

Cisco.com

Distribution Layer—Cat6K

```
! Trust CoS from the Layer 2 only Catalyst 4000 Access Switch
interface GigabitEthernet2/2
     description trunk port to layer 2-only cat4k
     no ip address
     wrr-queue cos-map 2 1 3
     wrr-queue cos-map 2 2 4
     mls qos vlan-based
     mls qos trust cos
     switchport
     switchport trunk encapsulation dot1q
     switchport mode trunk
! Trust CoS from the Layer 2 only 3500 Access Switch
interface GigabitEthernet3/1
     description trunk port to layer 2-only 3500
     no ip address
     wrr-queue cos-map 2 1 3
     wrr-queue cos-map 2 2 4
     mls qos vlan-based
     mls qos trust cos
     switchport
     switchport trunk encapsulation dot1q
     switchport mode trunk
```

Native-IOS 6000

Campus QoS—Access Layer

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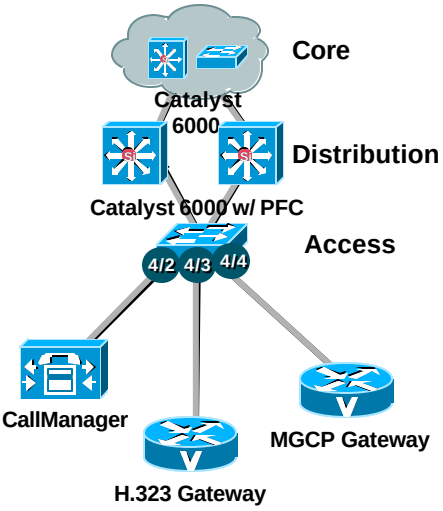
Control and Management Plane Traffic

- All VoIP Control Plane Traffic should be Classified as DSCP=AF31 in the VoIP Gateway or from the Cat6K PFC
  - Skinny Control: TCP 2000-2002
    - Skinny already classifies in CCM 3.0(5) and beyond
  - MGCP Control: UDP 2427 and TCP 2428
  - H.323 Control: TCP 1720
    TCP 11000-11999
    - H.323 and MGCP Call Control traffic can be classified from IOS 12.2(1)T



Campus QoS—Classification

Cisco.com

Control and Management Plane Traffic

H.323 RTP and VoIP Control Channel Classification

```
ip qos dscp ef media
ip qos dscp af31 signaling
```

MGCP VoIP Control Channel Classification

```
cat6k-access> (enable) set qos acl ip ACL_VOIP_CONTROL dscp 26
udp any any eq 2427
cat6k-access> (enable) set port qos 4/2 port-based
cat6k-access> (enable) set port qos 4/4 port-based
cat6k-access> (enable) commit qos acl ACL_VOIP_CONTROL
cat6k-access> (enable) set qos acl map ACL_VOIP_CONTROL 4/2
cat6k-access> (enable) set qos acl map ACL_VOIP_CONTROL 4/4
```

General Campus Recommendations

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- Use switches that support multiple queues on both access and uplink ports and in-line power in the wiring closet
  - 2900 XL
  - 3500 XL (not GigaStacked; Daisy Chain OK)
  - 4000
  - 6000
- If 5000 is used in the wiring closet, use Saint 5 (10/100) linecards for uplinks or use 1 uplink for voice VLANs and one uplink for data VLANs
  - If 5000 is used in the wiring closet, use Saint 5 linecards

Agenda

Cisco.com

- Quality Concerns with IP Telephony and Multimedia Applications
- General AVVID QoS Design Guidelines
- Connecting the IP Phone
- Designing the Campus
- Enabling the WAN
- Managing the QoS Infrastructure

QoS in the WAN

Cisco.com

General Guidelines

- Use LLQ anytime VoIP over the WAN is involved
- Traffic shaping is a requirement for frame-relay/ATM environments
- Use LFI techniques for all links below 768Kbps
  - Don't use LFI for any video over IP applications
- TX-ring sizes may require modifications
- Properly provision the WAN bandwidth
- Call admission control is a requirement where VoIP calls can over-subscribe the provisioned BW
- Use cRTP carefully

IOS Recommendations

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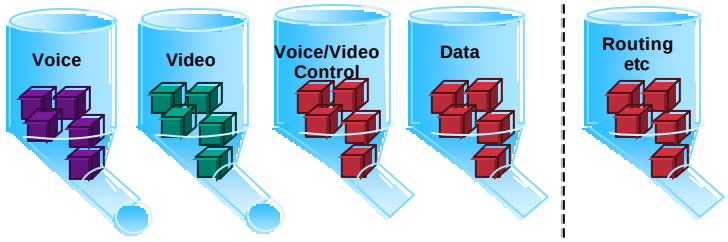
Media	Minimum IOS	Prioritization	LFI	Traffic Shaping
Leased Lines	12.1(2)T	LLQ	MLPPP	N/A
Frame-Relay	12.2(1)T	LLQ	FRF.12	Shape to CIR
ATM	12.1(6)	Per VC LLQ	MLPPP over ATM	Shape to Guaranteed Portion to BW
Frame-Relay to ATM Interworking	12.1(5)T*	Per VC LLQ	MLPPP over ATM and Frame-Relay	Shape to Guaranteed Portion to BW

Sources of Trouble for VoIP

Cisco.com

Provisioning

Voice Is Not Free—Especially on Low Speed Links—Engineer the Network for Data, Voice, and Video



LLQ = 33%

Sum of Traffic = 75%

Link Capacity

Link Capacity = (Min BW for Voice + Min BW for Video + Min BW for Data) / 0.75

Calculating VoIP Bandwidth Requirements

Cisco.com

Provisioning

CODEC	Sampling Rate	Voice Payload in Bytes	Packets per Second	Bandwidth per Conversion
G.711	20 msec	160	50	80 kbps
G.711	30 msec	240	33	74 kbps
G.729A	20 msec	20	50	24 kbps
G.729A	30 msec	30	33	18 kbps

A More Accurate Method for Provisioning is to Include the Layer 2 Headers into the Bandwidth Calculations

CODEC	Ethernet 14 Bytes of Header	PPP 6 Bytes of Header	ATM 53 Bytes Cells with a 48 Byte Payload	Frame-Relay 4 Bytes of Header
G.711 at 50 pps	85.6 kbps	82.4 kbps	106 kbps	81.6 kbps
G.711 at 33 pps	77.6 kbps	75.5 kbps	84 kbps	75 kbps
G.729A at 50 pps	29.6 kbps	26.4 kbps	42.4 kbps	25.6 kbps
G.729A at 33 pps	22.2 kbps	20 kbps	28 kbps	19.5 kbps

cRTP Update

Cisco.com

Miscellaneous VoIP QoS Tools

- Fast switching enhancements in 12.1(1)T and 12.1(2)T are interface specific; also, each QoS feature might take the switching back to process switched; read release notes carefully
- 12.2.1T (target): cRTPovPPPovATM-AAL5
  - PPP definitely
  - MLPPP under investigation
- cRTP over IETF FR VCs
  - Submitted a FR forum proposal for carrying cRTP in FR encap

cRTP VoIP Bandwidth Calculations

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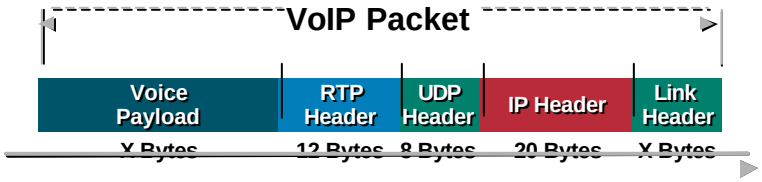
Miscellaneous VoIP QoS Tools



CODEC	PPP 6 Bytes of Header	ATM 53 Bytes Cells with a 48 Byte Payload	Frame-Relay 4 Bytes of Header
G.711 at 50 pps	68 kbps	N/A	67 kbps
G.729A at 50 pps	12 kbps	N/A	11.2 kbps
G.729A at 33 pps	10.5 kbps	N/A	10 kbps

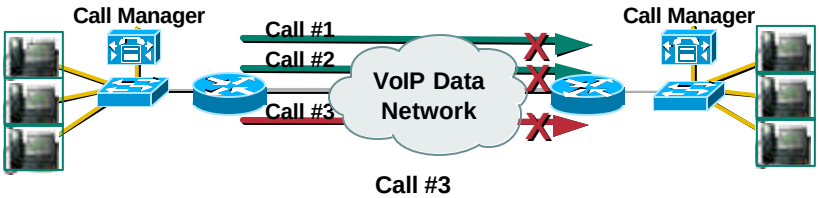
Sources of Trouble for VoIP

Cisco.com

Call Admission Control

"Protecting Voice from Voice"

Example:
WAN Bandwidth Can Only Support 2 Calls
What Happens when 3rd Call Attempted?



Call #3
Causes Poor Quality for ALL Calls

Need—To Prevent Third Call from Traversing IP WAN

PQ-CBWFQ (Low Latency Queuing)

Cisco.com

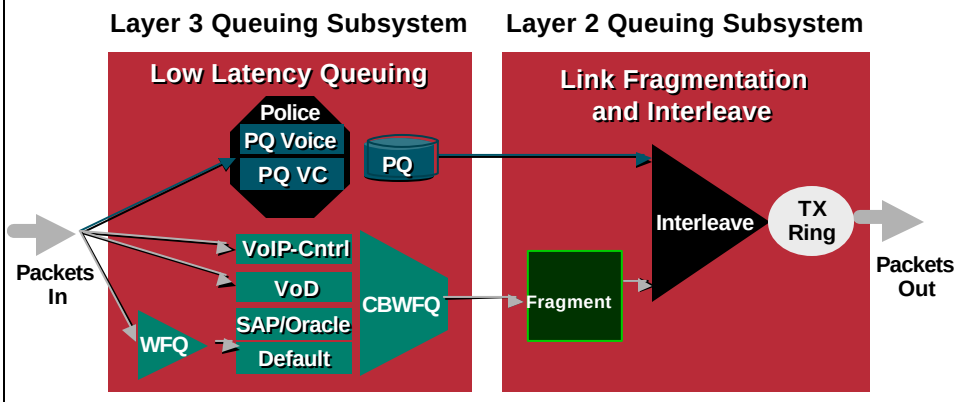
Queuing

- **Operation**
  - PQ is policed to BW to ensure other traffic is not starved
  - Rate limit is per class, even if multiple classes point traffic to PQ
  - Over-subscription of minimum possible BW is not allowed
  - "Bandwidth" and "priority" mutually exclusive
- **BW in the priority class**
  - Max allowable BW for "priority" classes is mincir (frame-relay)
  - Recommended max BW for "priority" classes is 33%
  - In order to take cRTP into account:
    - 7500—12.2(1) - Careful
    - 7200—12.2(1)T
    - 26/3600—12.2(1)

Low-Latency Queuing Logic Tree

Cisco.com

Queuing



LLQ Example—WAN Router

Cisco.com

VoIP—Queuing

```
class-map VoIP-RTP
  match access-group 100
class-map VoIP-Control
  match access-group 101
!
policy-map QoS-Policy
  class VoIP-RTP
    priority 100
  class VoIP-Control
   bandwidth 8
  class class-default
   fair-queue
!
!  Voice RTP Traffic
access-list 100 permit ip any any dscp cs5
access-list 100 permit ip any any dscp ef
!
!  Voice Control Traffic
access-list 101 permit ip any any dscp cs3
access-list 101 permit ip any any dscp af31
```

Leased Lines: 12.0.7T

```
interface Multilink 1
 service-policy output QoS-Policy
```

ATM: 12.0.7T

```
interface ATM1/0.1 point-to-point
 service-policy output QoS-Policy
```

VoIPovFR: 12.1.2T

```
map-class frame voipofr
  frame cir 128000
  frame mincir 64000
  frame bc 1000
  frame frag 160
 service-policy output QoS-Policy
```


LLQ Example—WAN Router

Cisco.com

Video—Queuing

```
class-map Video-Conf
  match access-group 102
class-map Streaming-Video
  match access-group 103
!
policy-map QoS-Policy
   class Video-Conf
     priority 450 30000
   class Streaming-Video
    bandwidth 150
   class class-default
    fair-queue
!
!  Video-Conf Traffic
access-list 102 permit ip any any dscp cs4
access-list 102 permit ip any any dscp af41
!
!  Streaming Traffic
access-list 103 permit ip any any dscp cs1
access-list 103 permit ip any any dscp af13
```

Leased Lines: 12.0.7T

```
interface Multilink 1
 service-policy output QoS-Policy
```

ATM: 12.0.7T

```
interface ATM1/0.1 point-to-point
 service-policy output QoS-Policy
```

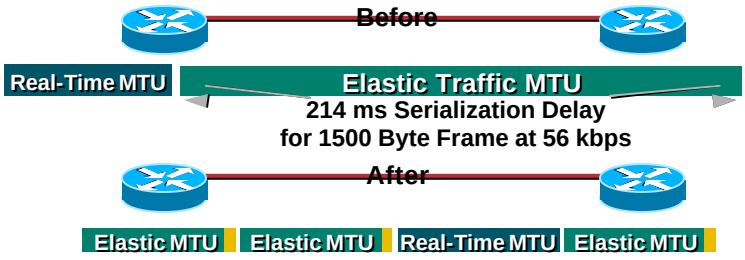
FR: 12.1.2T

```
map-class frame vcofr
  frame cir 128000
  frame mincir 64000
  frame bc 1000
  frame frag 160
 service-policy output QoS-Policy
```


Slow Link Efficiency Tools

Cisco.com

Fragmentation and Interleave Not Needed on Links Greater than 768 kbps



Mechanisms

Pt to Pt Links: MLPPP with Fragmentation and Interleave
Frame Relay: FRF.12—12.1(5)T
ATM: MLPPP over ATM—12.1(5)T
ATM/Frame-Relay Interworking: MLPPP over ATM and Frame Relay—12.1(5)T

Fragment Size for MLPPP over ATM:
Fragment_Size = (48 * Number_of_Cells)—10–8

Fragment Size Recommendations

Cisco.com

LFI Fragment Information

Serialization Delay Matrix

	64 Bytes	128 Bytes	256 Bytes	512 Bytes	1024 Bytes	1500 Bytes
56 kbps	9 ms	18 ms	36 ms	72 ms	144 ms	214 ms
64 kbps	8 ms	16 ms	32 ms	64 ms	128 ms	187 ms
128 kbps	4 ms	8 ms	16 ms	32 ms	64 ms	93 ms
256 kbps	2 ms	4 ms	8 ms	16 ms	32 ms	46 ms
512 kbps	1 ms	2 ms	4 ms	8 ms	16 ms	23 ms
768 kbps	640 used	1.2 ms	2.6 ms	5 ms	10 ms	15 ms

Fragmentation Size Matrix
(Based on 10 msec Delay)

Link Speed	Frag Size
56 kbps	70 Bytes
64 kbps	80 Bytes
128 kbps	160 Bytes
256 kbps	320 Bytes
512 kbps	640 Bytes
768 kbps	1000 Bytes
1536 kbps	2000 Bytes

TX-Ring Sizing

Cisco.com

Misc. VoIP QoS Tools

- TX-Ring (TX-Queue on 7500 RSP) is an un-prioritized FIFO buffer which holds packets just before media transmission
- Used to make sure enough packets are queued in order to maximize available BW
- Will add to E-2-E delay numbers because serialization delay really equals:

  Serialization delay * number of packets in the TX-Ring buffer

Media	Default TX-Ring Buffer Sizing (Packets)
PPP	6
MLPPP	2
ATM	8192—Must Be Changed For Low Speed Vcs
Frame-Relay	64 (Per Main T1 Interface)

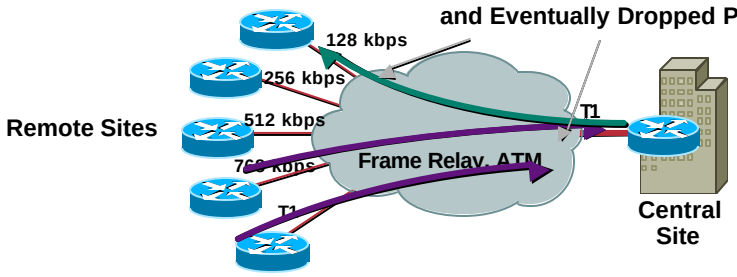
Link Speed /CIR/PVC	Default TX-Ring Buffer Sizing (Packets)
128 kbps	3
192 kbps	3
256 kbps	3
512 kbps	4
768 kbps	6

Traffic Shaping—Why?

Cisco.com

Misc. VoIP QoS Tools

Result:
Buffering which Will Cause Delay and Eventually Dropped Packets



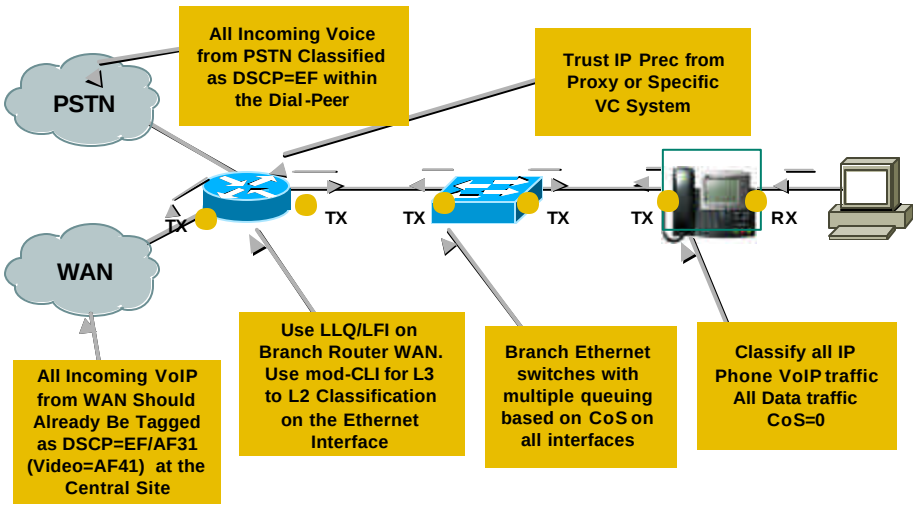
1. **Central to remote site speed mismatch**
2. **To avoid remote to central site over-subscription**
3. **To prohibit bursting above committed rate**

What are you guaranteed above you committed rate?

Branch QoS

Cisco.com

General Guidelines



QoS In the Branch Office

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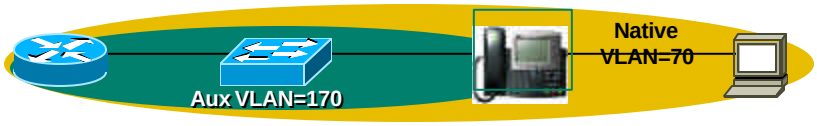
- If any VoIP over the WAN is part of the design, advanced QoS tools are a requirement; specifically, LLQ and LFI
- Branch router will typically be 1750, 2600, 3600, Cat4k or Jobim
  - All of these support VoIP gateway interfaces: classify VoIP traffic
- Only the 2600 and 3600 support 802.1Q/p…branch switch needs router to set 802.1p for queuing (10/100 interfaces)
- Catalyst scheduling capabilities depends on hardware:
  - Catalyst 2900 XL or 3500 XL
  - Catalyst 4000
  - Catalyst 6000

Branch Office Design

Cisco.com

802.1Q Trunking



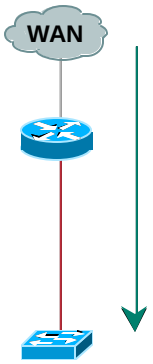

```
interface FastEthernet1/0
 description Catalyst 4000 Branch Office Switch
 no ip address
 ip route cache policy
 no ip mroute-cache
 load-interval 30
 speed 100
 full-duplex
!
interface FastEthernet1/0.70
 description native subnet 10.1.70.0 data
 encapsulation dot1Q 70
 ip address 10.1.70.1 255.255.255.0
 service-policy output output-L3-to-L2
 no ip mroute-cache
!
interface FastEthernet1/0.170
 description native subnet 10.1.170.0 voice
 encapsulation dot1Q 170
 ip address 10.1.170.1 255.255.255.0
 service-policy output output-L3-to-L2
```

```
cat4k> (enable) set vlan 70 name data70
cat4k> (enable) set vlan 170 name voice170
cat4k> (enable) set vlan 70 2/1-48
cat4k> (enable) set port host 2/1-48
cat4k> (enable) set port auxiliaryvlan 2/1-48
170
cat4k> (enable) set port speed 2/1-49  auto
cat4k> (enable) set trunk 2/49 on dot1q 1-1005
```


Layer 3 to Layer 2 Classification Mapping at the Branch

Cisco.com

Requires the mod-cli Commands Available in IOS 12.1(5)T*




```
class-map L3-to-L2-VoIP-RTP
 match ip dscp EF
class-map L3-to-L2-Video-Conf
 match ip dscp AF41
class-map L3-to-L2-VoIP-Control
 match ip dscp AF31
!
policy-map output-L3-to-L2
 class L3-to-L2-VoIP-RTP
    set cos 5
 class L3-to-L2-Video-Conf
    set cos 4
 class L3-to-L2-VoIP-Control
    set cos 3
!
interface e0/0
 service-policy output output-L3-to-L2
```


Branch Office Design

Cisco.com

Single Subnet


```
interface FastEthernet1/0
 mac-address 0000.2600.0001
 ip address 10.1.40.1 255.255.255.0
 ip helper-address 10.1.10.10
 service-policy output output-L3-to-L2
 no ip mroute-cache
 load-interval 30
 speed 100
 full-duplex
```

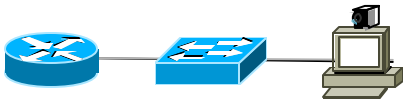
```
interface FastEthernet0/2
  description Port to IP Phone in single
  subnet
  switchport trunk encapsulation dot1q
  switchport trunk native vlan 40
  switchport mode trunk
  switchport voice vlan dot1p
  spanning-tree portfast
 !
 interface FastEthernet0/15
  description Port to 1750 Router in
  single subnet
  load-interval 30
  duplex full
  speed 100
  switchport access vlan 40
```


Branch Office Video Conf Designs

Cisco.com

Video Conf Zone Design Specific

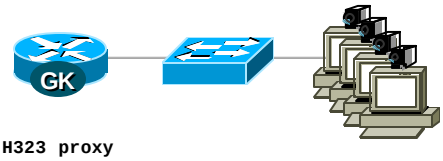
Single WAN Zone



10.70.249.200

```
class-map Video-Conf
  match access-group 102
!
policy-map QoS-Policy
  class Video-Conf
    priority 450 30000
  class class-default
   fair-queue
!
!  Video-Conf Traffic
access-list 102 permit ip host
  10.70.249.200 any dscp cs4
access-list 102 permit ip host
  10.70.249.200 any dscp af41
```

Multiple WAN Zones




```
H323 proxy
!
interface FastEthernet1/0.249
 descrip native subnet 10.70.249.0 data
 encapsulation dot1Q 70
 ip address 10.70.249.1 255.255.255.0
 service-policy output output-L3-to-L2
 no ip mroute-cache
 h323 interface
 h323 qos ip-precedence 4
 h323 h323-id vail-px@vail.com
 h323 gatekeeper ipaddr 10.70.249.254
```


WAN QoS—Leased Lines

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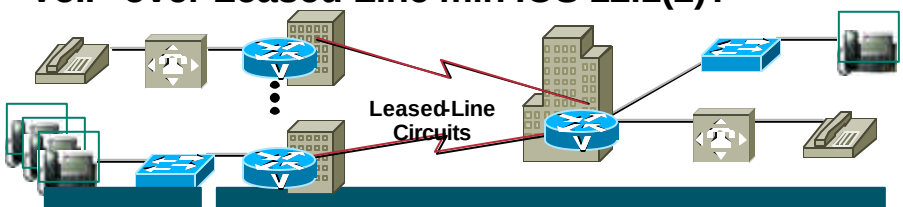
VoIP over Leased-Line min IOS 12.1(2)T



Queuing	**Low-Latency Queuing** VoIP Bearer Plane PQ'd by IP Prec/DSCP (5/EF) Classification VoIP Control Plane CBWFQ'ing by IP Prec/DSCP (3/24) Classification
Video	**T1 Clock or Above** Video Conf PQ'd by IP Prec/DSCP (4/34) Classification Streaming Video CBWFQ'ing by IP Prec/DSCP (1/14) Classification
LFI	**MLPPP** Link Speeds < 768kbps Fragment Size = Max_Allowed_Jitter / (1 Byte / Line Speed in kbps)
cRTP	Supported

AVVID over PPP QoS Example

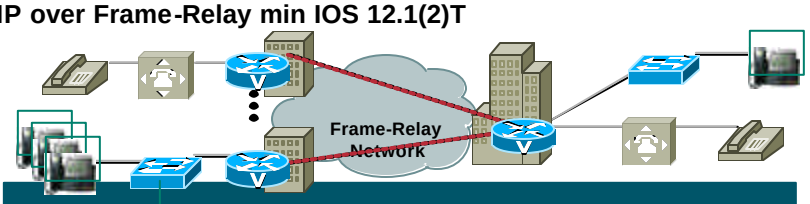
Cisco.com

```
interface Multilink1
 ip address 10.1.61.1 255.255.255.0
 ip tcp header-compression iphc-format
 no ip mroute-cache
 load-interval 30
 service-policy output QoS-Policy
 ppp multilink
 ppp multilink fragment-delay 10
 ppp multilink interleave
 multilink-group 1
 ip rtp header-compression iphc-format
!
interface Serial0
 bandwidth 256
 no ip address
 encapsulation ppp
 no ip mroute-cache
 load-interval 30
 no fair-queue
 ppp multilink
 multilink-group 1
```


WAN QoS—Frame-Relay

Cisco.com

VoIP over Frame-Relay min IOS 12.1(2)T



Queuing	Low-Latency Queuing per VC VoIP Bearer Plane PQ'd by IP Prec/DSCP (5/EF) Classification VoIP Control Plane CBWFQ'ing by IP Prec/DSCP (3/24) Classification
Video	T1 Clock or Above Video Conf PQ'd by IP Prec/DSCP (4/34) Classification Streaming Video CBWFQ'ing by IP Prec/DSCP (1/14) Classification
Traffic Shaping	Frame-Relay Traffic Shaping Shape to CIR / [CIR +(Flags+CRC)] Bc = CIR/100 Be = 0 MinCIR >= Sum of all configured queues
LFI	MLPPP Link Speeds < 768kbps Fragment Size = Max_Allowed_Jitter / (1 Byte / Line Speed in kbps)
cRTP	Supported

AVVID over Frame-Relay QoS Example

Cisco.com

```
interface Serial1
 no ip address
 encapsulation frame-relay
 load-interval 30
 frame-relay traffic-shaping
!
interface Serial1.71 point-to-point
 bandwidth 256
ip address 10.1.71.1 255.255.255.0
 frame-relay interface-dlci 71
  class VoIP
!
map-class frame-relay VoIP
 frame-relay cir 250000
 frame-relay bc 1000
 frame-relay be 0
 frame-relay mincir 250000
 no frame-relay adaptive-shaping
 service-policy output QoS-Policy
 frame-relay fragment 320
```

256000 * 320/324
Rounded Down

WAN QoS—ATM

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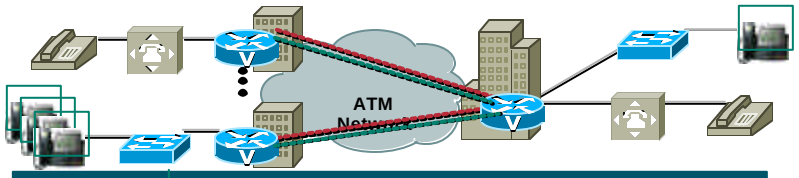
VoIP over ATM-Relay 12.1(5)T



Queuing	Low-Latency Queuing per VC VoIP Bearer Plane PQ'd by IP Prec/DSCP (5/EF) Classification VoIP Control Plane CBWFQ'ing by IP Prec/DSCP (3/24) Classification
Video	T1 Clock or Above Video Conf PQ'd by IP Prec/DSCP (4/34) Classification Streaming Video CBWFQ'ing by IP Prec/DSCP (1/14) Classification
Traffic Shaping	Generic Traffic Shaping Shape to low VC
LFI	MLPPP over ATM in 12.1(5)T
cRTP	Not Supported

AVVID over ATM QoS Example

Cisco.com

```
interface ATM2/0
 no ip address
 no ip mroute-cache
 no shutdown
 atm pvc 1 0 16 ilmi
 no atm ilmi-keepalive
!
interface ATM2/0.37 point-to-point
 pvc cisco37 0/37
  tx-ring-limit 7
  abr 256 256
  protocol ppp Virtual-Template2
 !
!
interface Virtual-Template2
 bandwidth 256
 ip address 10.1.37.52 255.255.255.0
 service-policy output QoS-Policy
 ppp authentication chap
 ppp chap hostname HQ_7200
 ppp chap password 7 05080F1C2243
 ppp multilink
 ppp multilink fragment-delay 10
 ppp multilink interleave
```


WAN QoS—ATM to Frame Relay

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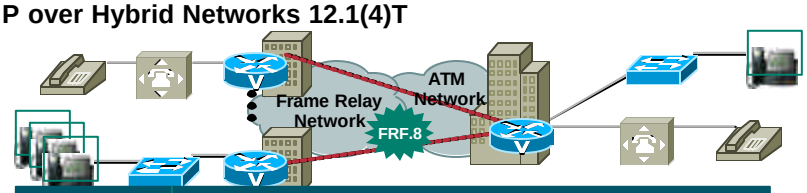
VoIP over Hybrid Networks 12.1(4)T



Queuing	Low-Latency Queuing per VC VoIP Bearer Plane PQ'd by IP Prec/DSCP (5/EF) Classification VoIP Control Plane CBWFQ'ing by IP Prec/DSCP (3/24) Classification
Video	T1 Clock or Above Video Conf PQ'd by IP Prec/DSCP (4/34) Classification Streaming Video CBWFQ'ing by IP Prec/DSCP (1/14) Classification
Traffic Shaping	Generic Traffic Shaping Shape to low VC Frame-Relay Traffic Shaping Shape to CIR / [CIR + (Flags+CRC)] Bc = 1000 Be = 0 MINCIR >= Sum of all configured queues
LFI	MLPPP over ATM and Frame-Relay in 12.1(5)T
cRTP	Not Supported

AVVID over ATM to Frame Relay Interworking QoS Example

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Remote Frame-Relay Configuration

```
interface Serial6/0
 description T1 to Frame Relay switch
 no ip address
 encapsulation frame-relay
 load-interval 30
 no arp frame-relay
 frame-relay traffic-shaping
!
interface Serial6/0.73 point-to-point
 description 3640
 no arp frame-relay
 frame-relay interface-dlci 73 ppp
Virtual-Template2
  class VoIP-256kbs
!
interface Virtual-Template2
 bandwidth 254
 ip address 10.1.37.51 255.255.255.0
 service-policy output QoS-Policy
 ppp authentication chap
 ppp chap hostname R72HQ
 ppp chap password 7 05080F1C2243
 ppp multilink
 ppp multilink fragment-delay 10
 ppp multilink interleave
```

Central ATM Configuration

```
interface ATM2/0
 no ip address
 no ip mroute-cache
 no shutdown
 atm pvc 1 0 16 ilmi
 no atm ilmi-keepalive
!
interface ATM2/0.37 point-to-point
 pvc cisco37 0/37
  tx-ring-limit 7
  abr 256 256
  protocol ppp Virtual-Template2
 !
!
interface Virtual-Template2
 bandwidth 254
 ip address 10.1.37.52 255.255.255.0
 service-policy output QoS-Policy
 ppp authentication chap
 ppp chap hostname HQ_7200
 ppp chap password 7 05080F1C2243
 ppp multilink
 ppp multilink fragment-delay 10
 ppp multilink interleave
```


WAN QoS—ATM to Frame Relay

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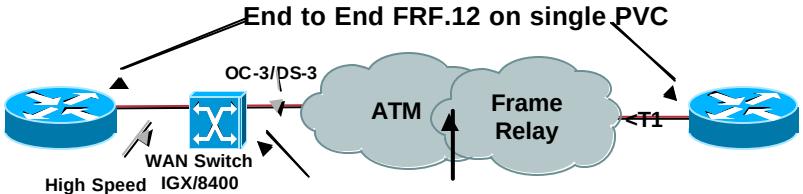
VoIP over Hybrid Networks—IGX Solution



FRF.8 Service Inter-working
Occurs in the Carrier AND Gets Reversed
at the IGX

Characteristics

1. Allows for L2 LFI (FRF.12) on a single PVC
2. Tested and works
3. Overcomes shortcomings of carriers not providing FRF.12 in cloud

Caveats

1. EXPENSIVE

Agenda

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- Quality Concerns with IP Telephony and Multimedia Applications
- General AVVID QoS Design Guidelines
- Connecting the IP Phone
- Designing the Campus
- Enabling the WAN
- Managing the QoS Infrastructure

Campus Queue Configuration

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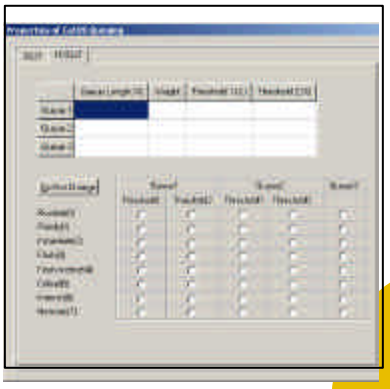
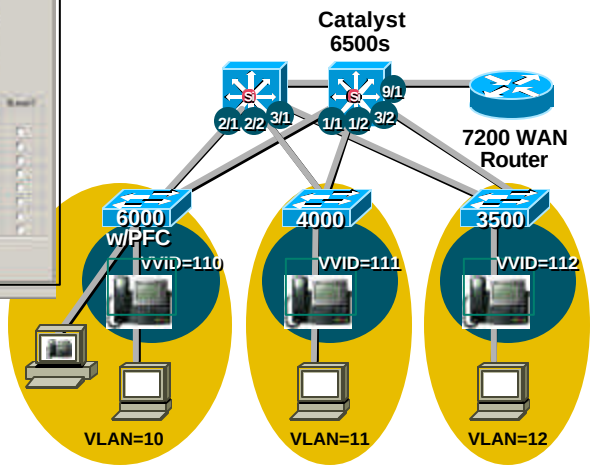
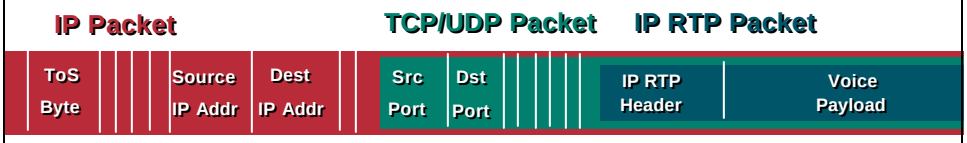
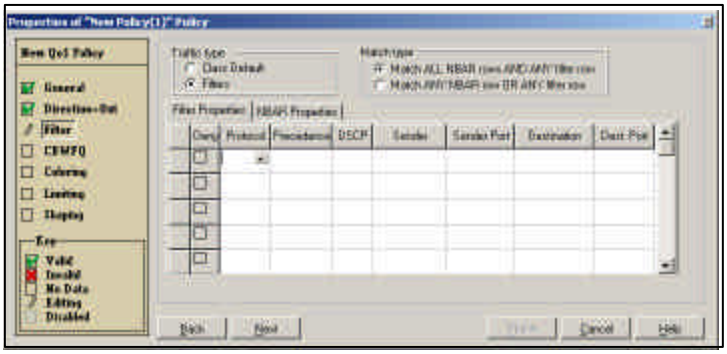




Identifying Packets for Service Treatment

Cisco.com





VVT-213
2913_05_2001_c1 97

Enabling LLQ with QPM

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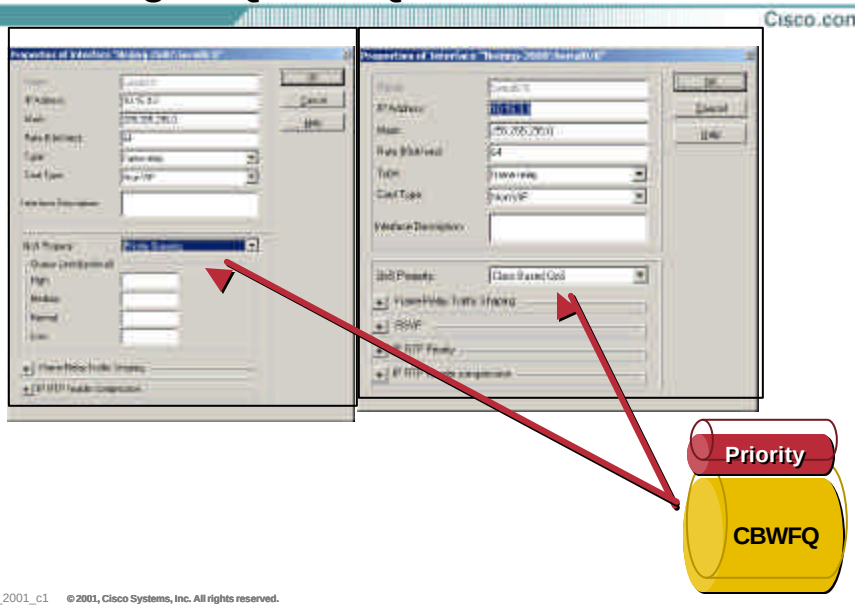
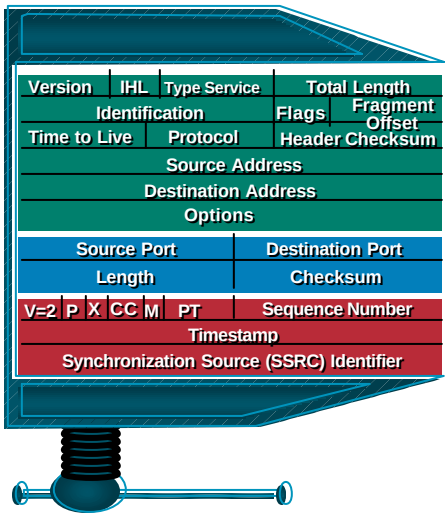


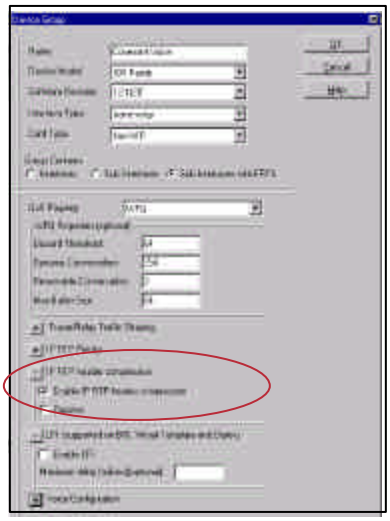
VVT-213
2913_05_2001_c1 98

Presentation_ID.scr

Configuring cRTP

Cisco.com

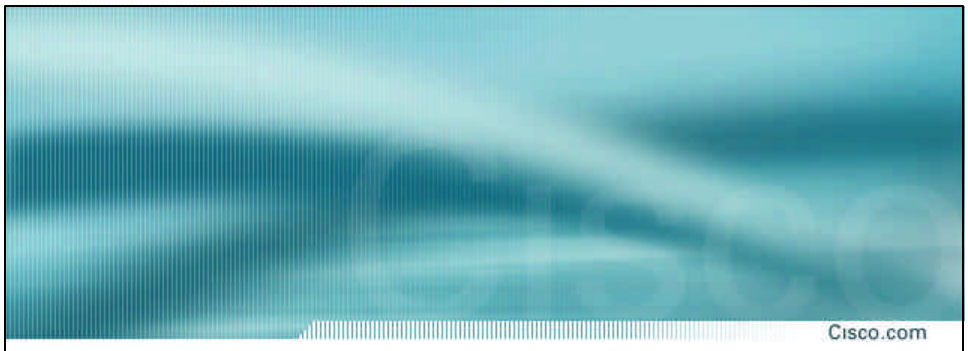




What's Coming…

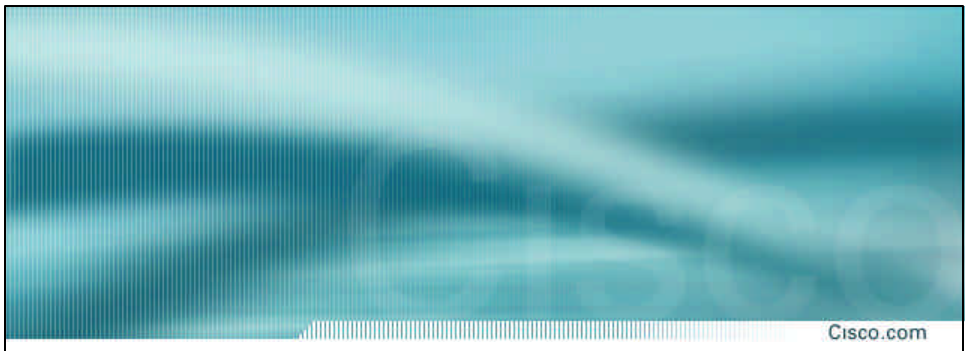
Cisco.com

- Cisco-wide consensus on voice control plane classification—completed
- Video QoS additions to QoS design guide — completed
- QPM Integration Testing and Appendix— completed
- Additional platform scalability testing—ongoing; check the ESE web site (9/01)



Deploying QoS for Voice and Video in IP Networks

Session VVT-213



Please Complete Your Evaluation Form

Session VVT-213